Data-driven diagnostics of terrestrial carbon dynamics over North America

Objectives:

- This study uses a data-driven approach to upscale eddy covariance (EC) flux observations from towers to continental scale.
- This is accomplished by integrating flux observations, meteorology, stand age, above-ground biomass and a proxy for canopy nitrogen concentrations from AmeriFlux and Fluxnet-Canada Research Network as well as a variety of satellite data streams from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensors.
- The data-driven approach employed was essentially an ensemble of regression models which generated rule-based predictive models, and is described in detail in this paper and in Xiao et al., 2008.
- EC flux observations from 94 sites across the United States and Canada were combined with satellite data streams and new ecological data, including stand age and above ground biomass, to generate flux estimates for North America from March 2000 to December 2012.
- The resulting gridded flux estimates were used to assess the magnitude, distribution and interannual variability of carbon fluxes for the U.S. and Canada.
- This study builds on and advances the authors' previous work with the AmeriFlux network of flux measurement sites across the U.S., where EC flux data were integrated with satellite observations to produce continuous estimates of gross primary production (GPP) and net ecosystem exchange (NEE) for the conterminous U.S, assessing the magnitude, distribution and interannual variability of the U.S. terrestrial carbon sink.
- Unlike the authors' previous upscaling studies for the conterminous U.S., this study includes recently available ecological data for aboveground biomass, stand age, and a proxy for canopy percent nitrogen (%N).
- This study was designed to upscale flux observations from EC flux sites to the continental scale and generate gridded flux estimates; to examine the magnitude and spatial pattern of carbon fluxes; to assess the interannual variability of carbon fluxes at the continental scale; and to evaluate the responses of these fluxes to extreme climate events and large disturbance.

New Science:

- The cross-validation results showed that the study's data-driven predictive models estimated carbon and water fluxes fairly well at the site level.
- The data-driven approach used was shown to upscale flux observations from AmeriFlux and Fluxnet-Canada sites to continental scale well.
- The study found that the mean annual gross primary production (GPP), ecosystem respiration (ER) and net ecosystem productivity (NEP) of the U.S. over the period 2001-2012 were 6.84, 5.31, and 1.10 PgC yr-1, respectively.
- The mean annual GPP, ER, and NEP of Canada over the same period were 3.91, 3.26, and 0.60 PgC yr-1, respectively.
- The mean nationwide annual NEP of natural ecosystems over that period was 0.53 PgC yr-1 for the U.S. and 0.49 PgC yr-1 conterminous U.S.
- The study estimate of the carbon sink for the conterminous U.S. was almost identical with the estimate of the first State of the Carbon Cycle Report (SOCCR).
- The mean annual carbon fluxes varied substantially over space, with GPP and ER generally exhibiting similar spatial patterns, although GPP was systematically higher than ER in most regions.

- Carbon fluxes exhibited relatively large interannual variability over the study period; the main sources of this variability were drought and disturbance.
- The study found that the annual GPP and NEP were strongly related to annual evapotranspiration (ET) for both the U.S. and Canada, demonstrating close coupling of the carbon and water cycles.
- The flux estimates are associated with several sources of uncertainties, including those arising from the spatial data used in prediction of carbon fluxes at continental scale, the flux data used to develop the predictive models, the inability of the approach to account for some controlling factors of carbon flux (such as disturbance type), and the inability to distinguish between C_3 and C_4 crops.
- The GPP and NEP estimates were slightly lower than estimates found in the authors' previous studies primarily because of the use of new ecological data, and are judged to be more accurate than previous estimates.

Significance:
- The exchange of carbon dioxide is a key measure of ecosystem metabolism and critical intersection between the terrestrial biosphere and the Earth's climate.
- General agreement exists that the terrestrial ecosystem in North America provides a large carbon sink; however, the size and distribution of the sink are not well quantified and there are large uncertainties related to sources of variability over space and time.
- Previous to this study, the growing number of studies upscaling EC flux observations, the effects of disturbance, stand age, and nitrogen availability – all important drivers of forest structure and function – have not been explicitly considered.
- The gridded flux estimates from this study provide an independent, alternative perspective on ecosystem carbon exchange over North America compared to conventional inventory approaches, ecosystem modeling, and atmospheric inversion.
- Despite the substantial advances in ecosystem modeling, large uncertainties still exist in the spatial and temporal variability of carbon fluxes.
- The assessment of full uncertainty remains a challenge in the realm of terrestrial ecosystem modeling and new techniques are needed to quantify the full uncertainty of flux estimates at regional to continental scales.
- Extreme events such as drought and disturbance, which are the primary sources of interannual variability of carbon fluxes over North America, are expected to become more frequent and more severe during the remainder of the 21st century, and they will likely have larger impacts on the terrestrial carbon dynamics.
- This study helps improve understanding of the variability in carbon dynamics over North America and quantification of associated uncertainties, which are essential for improving projections of the Earth's carbon-climate system under future climate conditions.
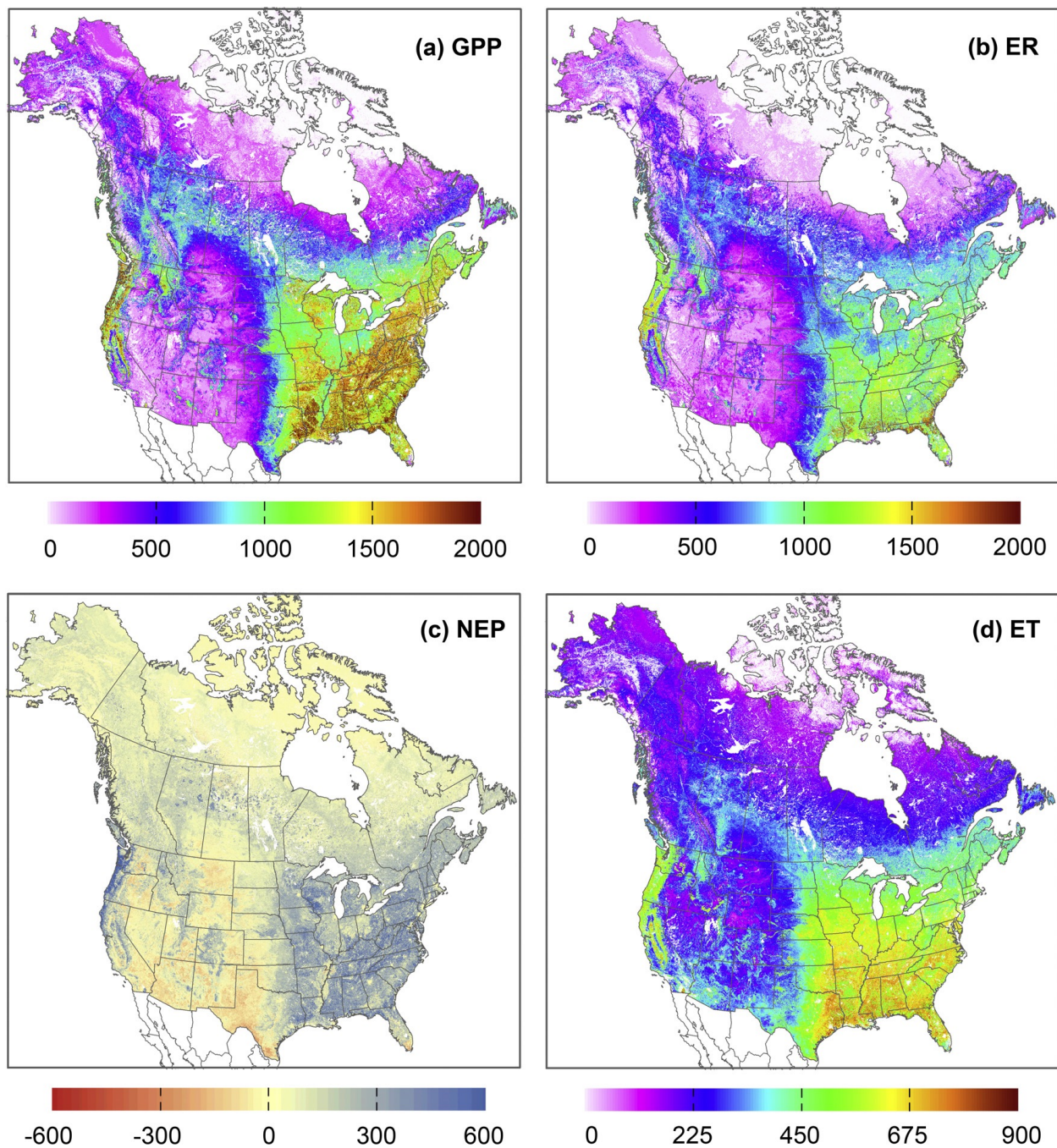
Mean annual carbon and water fluxes over North America for the period 2001–2012: (a) GPP); (b) ER; (c) NEP; and (d) ET. The units for carbon fluxes are g C m−2yr−1, and the units for ET are mm yr−1.
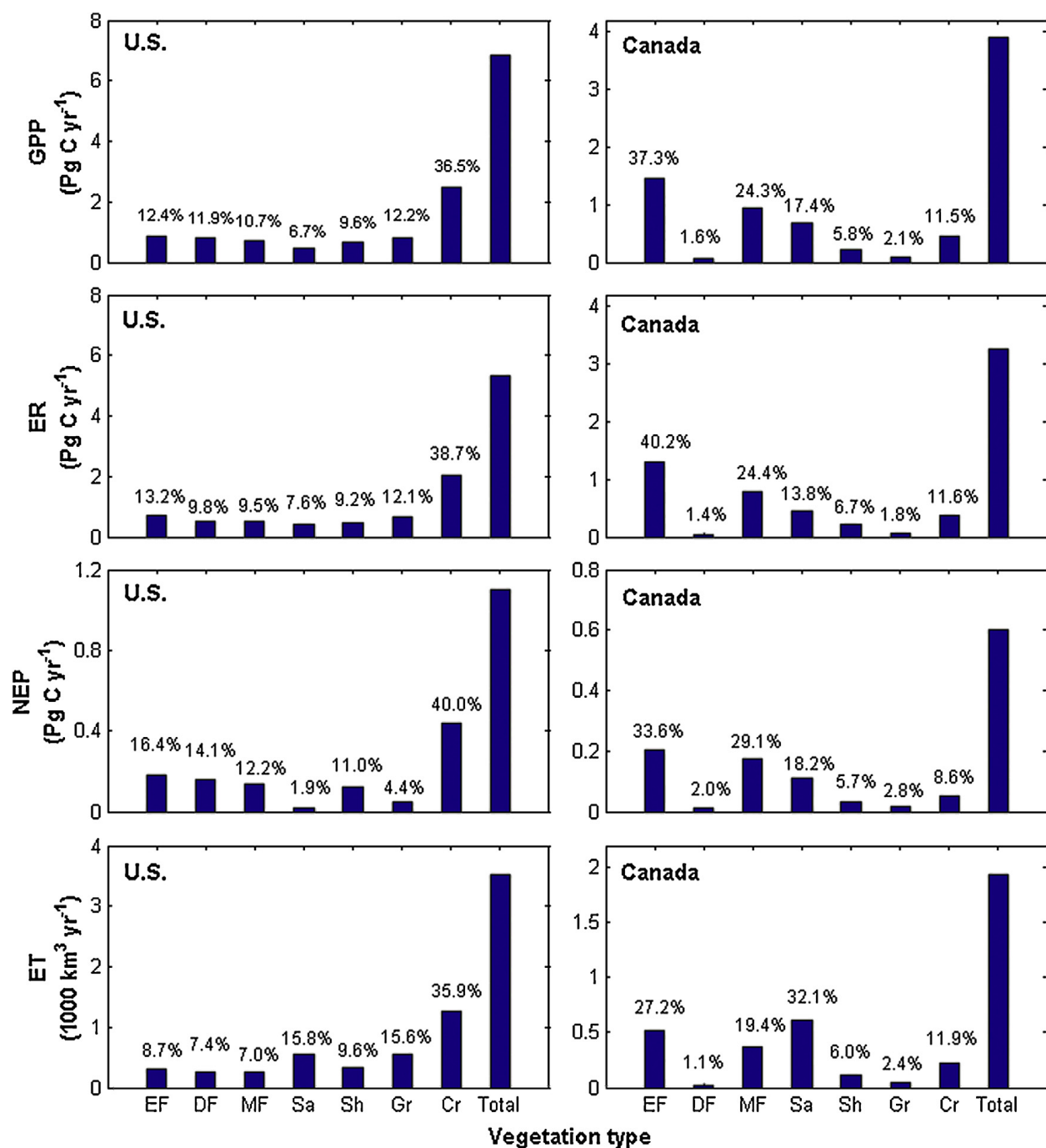
Total annual carbon and water fluxes averaged over the period 2001–2012 for the U.S. and Canada at the national scale and for each broad vegetation type. The broad vegetation types are: evergreen forests (EF), deciduous forests (DF), mixed forests (MF), savannas (Sa), grasslands (Gr), and croplands (Cr). The percentages stand for the proportions that each broad vegetation type accounts for the nationwide fluxes.